THE CLEANING EFFICIENCY OR SANITARY VALUE OF VACUUM CLEANERS.*

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Testing of vacuum cleaners.—Methods of cleaning have been tested in the past by determining the number of bacteria which are found in the air over and above those normally present. That is, they have been tested according to their ability to clean without raising a dust. One broom during the process of sweeping would introduce a certain number of bacteria into the air, another broom or process of sweeping would introduce only half as many and would therefore be considered twice as good. With the introduction of the vacuum cleaner this method is evidently insufficient to test its cleaning value. What one wants to determine here is the effectiveness of the apparatus in removing the bacteria from the floor or other article to be cleaned, for probably no vacuum cleaner, however inefficient, will raise much dust, although in this connection special attention is directed to the findings given below in regard to cleaners which exhaust into the air of the room being cleaned. What we want to know here is the proportion of dust and bacteria removed from the room by the cleaner. This is a difficult matter to test bacteriologically, and one which, so far as the writers know, has not been attempted before. None of the ordinary methods of bacteriological analysis are applicable. It seemed necessary, therefore, to devise a method. The problem, as it appeared to us, was to determine the number of bacteria on a given surface of floor or furniture; clean it and then determine the number of bacteria left. In this way it would be possible to determine the cleaning efficiency of a system measured in terms of bacteria removed.

The first method that suggested itself was to wipe a measured area of the surface to be cleaned with a sterile cotton swab moistened in sterile water, the cotton swab to be put into a flask of

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sterile water, used as the diluting medium. This idea was put into action and definite areas were marked out on the floor and the method tried out. Not one swab was used but a number consecutively until all the dirt appeared to be taken up. It was found impossible, however, to arrive at any definite conclusion as to the number of bacteria present, because of variations in different trials which apparently could not be overcome. While working at this problem, one of the writers had occasion to use some surgeon's adhesive tape and this suggested the idea that the principle involved here might be made use of in removing bacteria. Various adhesives were tried. The method which was finally agreed upon is as follows.

Discs of cheesecloth the size of a Petri dish are cut out, leaving a small protuberance on each of two sides. These protuberances are used later in raising the disc. The Petri dish, with its cloth disc, is sterilized in the hot-air oven. A thick gelatin is then prepared (20 gms. of gelatin to 100 c.c. water) and sterilized in the autoclave at 12 pounds pressure for 15 minutes. Special care must be taken to heat the autoclave rapidly and cool it down quickly, as it is imperative that the texture of the gelatin remain firm and tenacious. The gelatin is then quickly poured into the Petri dishes containing the cheesecloth and set away to harden in a cool place. Great care must be taken in handling the Petri dishes while the gelatin is still liquid since if it gets between the covers it will glue them together. The texture of the gelatin is at its best when 24 hours old.

Other materials needed for this work are flasks of sterile water, containing 50 c.c., 100 c.c., 200 c.c., and 1,000 c.c. The amount used will depend upon the condition of the surface to be tested. The flasks containing the sterile water should have wide mouths, such as Phillips beakers. Also sterile forceps, sterile pipettes, a sterile spatula, sterile Petri dishes, and a water bath should be at hand.

The adhesive disc should be carefully removed from a Petri dish with sterile forceps and then placed on the surface to be tested and pressed gently with a sterile spatula, so that the entire undersurface of the disc comes in contact with the surface to be tested.

The disc is then carefully picked up and placed in a sterile water blank. While doing this work great care must be taken so as not to handle the disc any more than is necessary. The water blanks are then placed in a bath, the water of which is not higher than 45° C. The discs will dissolve in about 15 minutes. When the gelatin is thoroughly dissolved the disc of cheesecloth will float in the water. Three plain agar plates are then poured, using one c.c. of the dilution in each. They are incubated at room tempera-

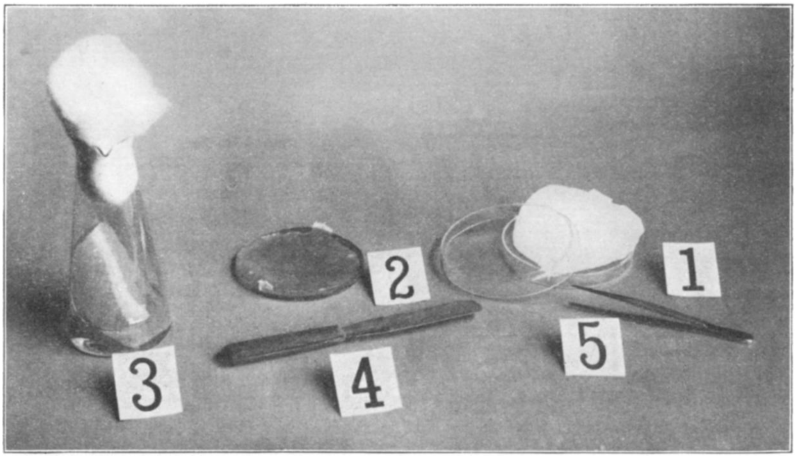

FIG. 1.—APPARATUS USED TO TEST VACUUM CLEANERS.

1. Petri dish with cheesecloth disc.
2. Gelatin disc in lower half of Petri dish.
3. Phillips beaker containing sterile water in which gelatin disc is being dissolved.

4 and 5. Sterile forceps and spatula.

ture for five days. When the colonies have developed, the number of bacteria per sq. cm. of the space tested is calculated.

Efficiency of adhesive discs in removing bacteria.—In order to prove that the adhesive discs take up the greater part of the bacteria, several discs were consecutively applied to the same area. When the first disc was plated out it was found that 22 bacteria per sq. cm. were taken up; when the second disc was applied to the same area, immediately afterward, less than one bacterium per sq. cm. was found. A third disc removed none per sq. cm. Two other tests made in a similar manner gave practically the same results.

The efficiency of the discs in removing bacteria was shown in another way. Black loam was sterilized in the oven and then pulverized in a mortar. This sterile, pulverized dirt then had mixed with it several loopfuls of *B. prodigiosus* taken from an agar culture. This dirt was sprinkled over a smooth surface, such as the top of a sterile Petri dish, and then the discs were applied to this, and dilutions and plates made in the ordinary way. An average of four tests showed that the first discs took up 7,166 bacteria per sq. cm., that the second discs found only 56 bacteria per sq. cm., and the third, less than one per sq. cm. It is thus seen that the first discs take up more than 99 per cent of the total number of bacteria on the surface, which is well within the limits of experimental error.

Number of bacteria on floors.—Having now worked out a method for removing bacteria and having tested the same, and having come to the conclusion that it removes fully 99 per cent of the bacteria on a surface, we may turn to a study of the number of bacteria found on ordinary surfaces and the efficiency of vacuum cleaning methods.

A study of the bacteria on a small area of a rather dirty laboratory floor showed 11,850 bacteria per sq. cm. In another place, the garret stairs of a dormitory, curiously enough, almost exactly the same number was found, i.e., 11,820. As an average of a number of trials in an ordinary room, 1,166 were found. At another time, on a stairway which had recently been cleaned, 68 bacteria were found as an average of a number of tests. In a recitation room 331 bacteria were found as an average of six tests, and 91 as an average of two tests in another room. In an exceptionally clean house, where a vacuum cleaner had been used for some months, an average of two different tests showed 84 bacteria per sq. cm.

VACUUM CLEANERS.

General description and types used.—When the vacuum cleaning system was introduced a few years ago, it was quite generally believed that the sanitary cleaning of buildings could be readily accomplished. But in the last few years there have been so many

different makes put upon the market, that vary greatly in their mechanical efficiency, that it would seem desirable to have some criterion for judging of their efficiency from a sanitary standpoint. If they differ greatly in mechanical efficiency they must also differ in cleaning power, and it was our purpose to test some of them. We have chosen two permanent systems, one in which the vacuum is produced by an electric fan, and the other by means of a steam aspirator. Of the portable types eight have been tested, three where the vacuum is produced by rapidly revolving fans, and two by bellows electrically driven, and two worked by hand. The experimental data on these different machines will be discussed separately.

Tests of Type A.—In Machine A the vacuum is obtained by an electric fan. This machine is installed in a women's dormitory and had been running about a year when the tests were made. The results obtained by an examination of the dirt on the floor before and after sweeping with the machine, together with the percentage of the efficiency, are shown in Table 1. This machine was further tested by means of the *B. prodigiosus* dirt and the results of this are shown in Table 2.

TABLE 1.

TESTS MADE ON A PERMANENT SYSTEM, VACUUM OBTAINED BY A FAN (BACTERIA PER SQ. CM.).

No. Exp.	Place	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	Dirty stairs	5,277	30	
2		5,072	46	
3		1,477	866	
Average		3,942	314	92 per cent
4	Well kept floor	33	0	
5		23	1	
6		55	5	
7		3,321*	7	
8		45	13	
9		23	2	
Average		1,166	9	99 per cent
10	Clean floor	25	4	
11		42	2	
12		28	0	
13		52	0	
14		58	2	
Average		68	3	86 per cent

* This large count is due to the presence of a piece of dirt.

In Table 1 tests were made under various conditions. In some cases the floors were very dirty; in other cases, very clean, and this probably accounts for the variation in efficiency. In experiments 1, 2, and 3, the floor was very dirty, and the bacteria were not easily dislodged by an air current, but were pulled off by the adhesive disc. In experiments 4 to 9, which were made on a very clean part of the floor, washed several times a week, the highest efficiency was obtained.

The tests with *B. prodigiosus* dirt (Table 2) show what this system can do when the material is not too firmly attached to the floor; and in the case of this machine practically all of the organisms were removed.

TABLE 2.

TESTS MADE IN THE PERMANENT SYSTEM, VACUUM OBTAINED BY A FAN (BACTERIA PER SQ. CM.), USING *B. prodigiosus*.

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	28,688	43	
2	29,963	26	
Average	29,325	35	99.88 per cent

Tests of Type B.—The vacuum in this case is produced by a steam aspirator. It is a single sweeper plant installed in a large gymnasium. The results obtained by an examination of the floor before and after cleaning are shown in Table 3, and the results of the *B. prodigiosus* tests are shown in Table 4.

TABLE 3.

TESTS MADE ON A PERMANENT SYSTEM, VACUUM OBTAINED BY STEAM ASPIRATOR (BACTERIA PER SQ. CM.).

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	110	17	
2	82	21	
3	33	5	
4	43	22	
5	83	8	
Average	117	24	79 per cent
6	19,600	7,000	
7	27,900	8,550	
8	35,700	8,250	
Average	27,700	7,933	72 per cent

TABLE 4.

TESTS MADE ON A PERMANENT SYSTEM, VACUUM OBTAINED BY STEAM ASPIRATOR (BACTERIA PER SQ. CM.), USING *B. prodigiosus*.

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	1,500	32	99.05 per cent
2	112,600	13,900	87.00 per cent

The first five tests were on a very clean floor; the last three on a very dirty one. The efficiency in both cases is about the same. It will be noticed that the percentage is considerably lower than with the previous type, due probably to the fact that the first machine moves a larger volume of air.

Tests of Type C.—Portable. Vacuum obtained by means of a rapidly revolving fan run by an electric motor. The testing was done in a recitation room, and the results obtained are shown in Table 5.

TABLE 5.

TESTS MADE ON PORTABLE MACHINE, VACUUM OBTAINED BY A FAN (BACTERIA PER SQ. CM.).

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	75	5	
2	35	1	
3	844	298	
4	508	73	
5	377	44	
6	154	97	
Average	331	86	74 per cent

Tests of Type D.—Fan type, electrically driven.

TABLE 6.

TESTS MADE ON PORTABLE MACHINE, VACUUM OBTAINED BY A FAN (BACTERIA PER SQ. CM.).

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	92	25	
2	48	22	
3	201	10	
Average	113	19	84 per cent

Tests of Type E.—Small portable machine, vacuum obtained by electric fan. Data shown in Table 7.

TABLE 7.

TESTS MADE ON PORTABLE MACHINE, VACUUM OBTAINED BY A FAN (BACTERIA PER SQ. CM.).

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	57	5	
2	125	15	
Average	91	10	89 per cent

Tests of Type F.—Vacuum produced in these machines by means of a bellows and electric power.

TABLE 8.

TESTS MADE ON PORTABLE MACHINE, VACUUM OBTAINED BY BELLOWS (BACTERIA PER SQ. CM.).

	No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
Type F. Machine 1	1	38	17	
	2	130	21	
	Average	84	19	77 per cent
Type F. Machine 2	3	45	25	
	4	122	12	
	Average	83	18	77 per cent

Tests of Type G.—A single machine of this type was tested. In it the vacuum was obtained by means of a bellows (hand driven).

TABLE 9.

TESTS MADE ON PORTABLE MACHINE, VACUUM OBTAINED BY BELLOWS (HAND DRIVEN) (BACTERIA PER SQ. CM.).

No. Exp.	No. Bacteria Found on Floor	No. Bacteria after Cleaning	Percentage of Bacteria Taken Up in Cleaning
1	11	6	
2	10	3	
Average	10	5	57 per cent

The efficiency of the permanently installed systems is much higher than in the case of the portable machines. Judged by the number of bacteria which they remove from the floor, the efficiency is 92 (A) and 75 (B) per cent as compared with 74 (C), 84 (D),

89 (E), 77 (F), 57 (G) per cent. The efficiency of the portables varies greatly, due to the differences in motive power, manner of construction, shape and size of brushes, etc.

Discharge of bacteria into air through exhaust pipe of machine.— In the permanently installed systems the bacteria in the dirt are taken out of the rooms entirely, and if the discharge pipe is properly located the bacteria removed are of no concern. In the portables, however, the condition is very different. All of these examined so far have discharged the air directly into the room. In some of them the air has been filtered or strained through a bag; in others the dust and bacteria are retained by a series of baffles. It is very evident upon consideration that it is ordinarily quite impossible to keep the bacteria from getting back into the room. In some of the machines examined, the bacteria pass through very readily; in others it is with greater difficulty, apparently, that their passage is accomplished. The testing of this point has been carried out by means of placing culture plates in front of the discharge pipe, and also by sucking dirt containing *B. prodigiosus* into the machine and then determining whether or not it escapes from the machine, and if so, the distance to which it is thrown, etc. The experiments were carried out as follows:

Dirt containing *B. prodigiosus* was sprinkled on the floor and sucked up in the machine to be tested. The machine was then taken into an entirely separate room where the number of bacteria in the air had just been determined. The machine was then set in motion and culture plates were exposed at various distances from the discharge pipe. The total number of bacteria on these plates were then determined, as well as *B. prodigiosus*. The results obtained are shown in the accompanying diagram (Fig. 2). This shows that a very considerable number of bacteria are thrown out of these machines and that some of them are thrown to a distance of nearly six feet.

It will be seen from the experiments that from a sanitary standpoint there is a great difference between the various types of machines. In some cases the bacteria are thrown back into the room in considerable numbers and for some distance. These

machines are able to take up the dirt and bacteria in varying degrees of perfectness, but since they allow the escape of the bacteria contained in the dirt they may be an actual menace to health. And it is possible to obtain abundant data to warrant health officers forbidding the use of these machines by traveling cleaners, since it must be very evident that if *B. prodigiosus* can be carried from one room to another, *B. tuberculosis* could be carried from one house to another.

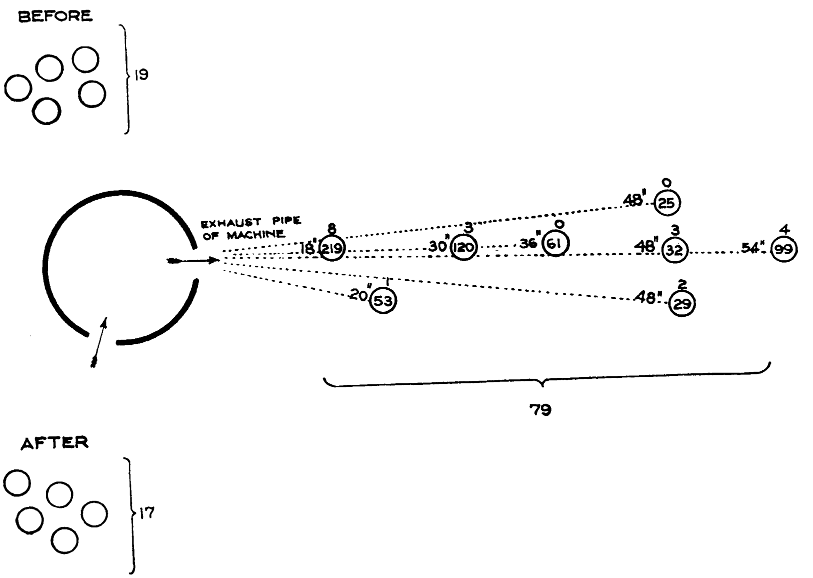

FIG. 2.—The large circle represents the vacuum cleaner; the small circles the culture plates; the dotted lines, the distances which are expressed in inches. The numbers inside of the small circles are the number of colonies of bacteria which developed. The figures just above the circles are the number of *B. prodigiosus* colonies. The figures on the brackets represent averages.

CONCLUSIONS.

1. Gelatin adhesive discs offer a satisfactory means of determining the number of bacteria on various surfaces, such as floors, furniture, etc.

2. Their use makes it possible to determine the cleaning efficiency of vacuum cleaners.

3. The permanently installed systems are most efficient.

4. The portables vary greatly in cleaning efficiency, some being quite efficient. Others have little cleaning power.

5. The portable machines, all of which allow the escape of the bacteria with the exhaust air, are of questionable value from a sanitary standpoint and under certain conditions they may be actually dangerous.